NASA-CR-205334

Final Report

Soot and Radiation Measurements in Microgravity Jet Diffusion Flames

NASA Grant : NAG3-1265 (4/1/1991 - 7/31/1995) 33/037

Project Scientist: Paul S. Greenberg
Mail Stop 110-3
Microgravity Combustion Branch
NASA Lewis Research Center

Date: December 15, 1996

Submitted by:
Jerry C. Ku, Associate Professor
Mechanical Engineering Department
Wayne State University
5050 Anthony Wayne Drive
Detroit, MI 48202
(313) 577-3814
FAX: (313) 577-8789

TABLE OF CONTENTS

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SUMMARY

The subject of soot formation and radiation heat transfer in microgravity jet diffusion flames is important not only for the understanding of fundamental transport processes involved but also for providing findings relevant to spacecraft fire safety and soot emissions and radiant heat loads of combustors used in air-breathing propulsion systems. Our objectives are to measure and model soot volume fraction, temperature, and radiative heat fluxes in microgravity jet diffusion flames. For this four-year project, we have successfully completed three tasks, which have resulted in new research methodologies and original results. First is the implementation of a thermophoretic soot sampling technique for measuring particle size and aggregate morphology in drop-tower and other reduced gravity experiments. In those laminar flames studied, we found that microgravity soot aggregates typically consist of more primary particles and primary particles are larger in size than those under normal gravity. Comparisons based on data obtained from limited samples show that the soot aggregate's fractal dimension varies within $\pm 20\%$ of its typical value of 1.75, with no clear trends between normal and reduced gravity conditions. Second is the development and implementation of a new imaging absorption technique. By properly expanding and spatially-filtering the laser beam to image the flame absorption on a CCD camera and applying numerical smoothing procedures, this technique is capable of measuring instantaneous full-field soot volume fractions. Results from this technique have shown the significant differences in local soot volume fraction, smoking point, and flame shape between normal and reduced gravity flames. We observed that some laminar flames become open-tipped and smoking under microgravity. The third task we completed is the development of a computer program which integrates and couples flame structure, soot formation, and flame radiation analyses together. We found good agreements between model predictions and experimental data for laminar and turbulent flames under both normal and reduced gravity. We have also tested in the laboratory the techniques of rapid-insertion fine-wire thermocouples and emission pyrometry for temperature measurements. These techniques as well as laser Doppler velocimetry and spectral radiative intensity measurement have been proposed to provide valuable data and improve the modeling analyses.

The research conducted during this program resulted in 6 publications, 4 of which in refereed journals, and 4 workshop or conference presentations. These publications and presentations are listed below, with copies of the 6 publications attached in sections numbered in corresponding Roman numerals.

LIST OF PUBLICATIONS

1. Hsu, P.-F., and Ku, J. C., 1994, "Radiative Heat Transfer in Finite Cylindrical Enclosures with Nonhomogeneous Participating Media," *J. Thermophys. Heat Transfer*, 8, 434-440.

2. Ku, J. C., Griffin, D. W., Greenberg, P. S., and Roma, J., 1995, "Buoyancy-Induced Differences in Soot Morphology," *Comb. Flame*, 102, 216-218.

3. Hsu, P.-F., and Ku, J. C., 1996, "Radiative Heat Transfer in Finite Cylindrical Enclosures with Nongray, Nonhomogeneous Soot/Gas Mixtures," *Radaitive Transfer -- I, Proc. 1st Int'l Symp. Radiative Transfer*, M. P. Menguc, ed., 372-386, Begell House Inc. Publisher, New York.

4. Ku, J. C., Tong, L., and Greenberg, P. S., 1996, "Measurements and Modeling of Soot Formation and Radiation in Microgravity Jet Diffusion Flames," *HTD-Vol. 335, Proc. ASME Heat Transfer Division, Vol. 4*, 261-270.

5. Greenberg, P. S., and Ku, J. C., 1997, "Soot Volume Fraction Maps for Normal and Reduced Gravity Laminar Acetylene Jet Diffusion Flames," *Comb. Flame*, 108, 227-230.

6. Greenberg, P. S., and Ku, J. C., 1997, " Soot Volume Fraction Imaging," to appear in *Appl. Opt.*

LIST OF PRESENTATIONS

1. Ku, J. C., Tong, L., Sun, J., Greenberg, P. S., and Griffin, D. W., 1992, "Soot Formation and Radiation in Turbulent Jet Diffusion Flames Under Normal and Reduced Gravity Conditions," 121-132, NASA CP-10113, Proc. 2nd Int'l Microgravity Combustion Workshop, Cleveland, Ohio, Sep. 15-17.

2. Ku, J. C., Tong, L., and Greenberg, P. S., 1995, "Detailed Modeling Analysis for Soot Formation and Radiation in Microgravity Gas Jet Diffusion Flames," 375-380, NASA CP-10174, Proc. 3rd Int'l Microgravity Comb. Workshop, Cleveland, Ohio, Apr. 11-13.

3. Hsu, P.-F., and Ku, J. C., 1995, "Radiative Heat Transfer in Finite Cylindrical Enclosures with Nongray, Nonhomogeneous Soot/Gas Mixtures," Int'l Symp. Radiative Transfer, Int'l Center for Heat and Mass Transfer (ICHMT), Kusadasi, Turkey, Aug. 14-18.

4. Ku, J. C., Tong, L., and Greenberg, P. S., 1996, "Measurements and Modeling of Soot Formation and Radiation in Microgravity Jet Diffusion Flames," Int'l Mech. Eng. Congress and Exposition (IMECE), Atlanta, Georgia, Nov. 17-22.